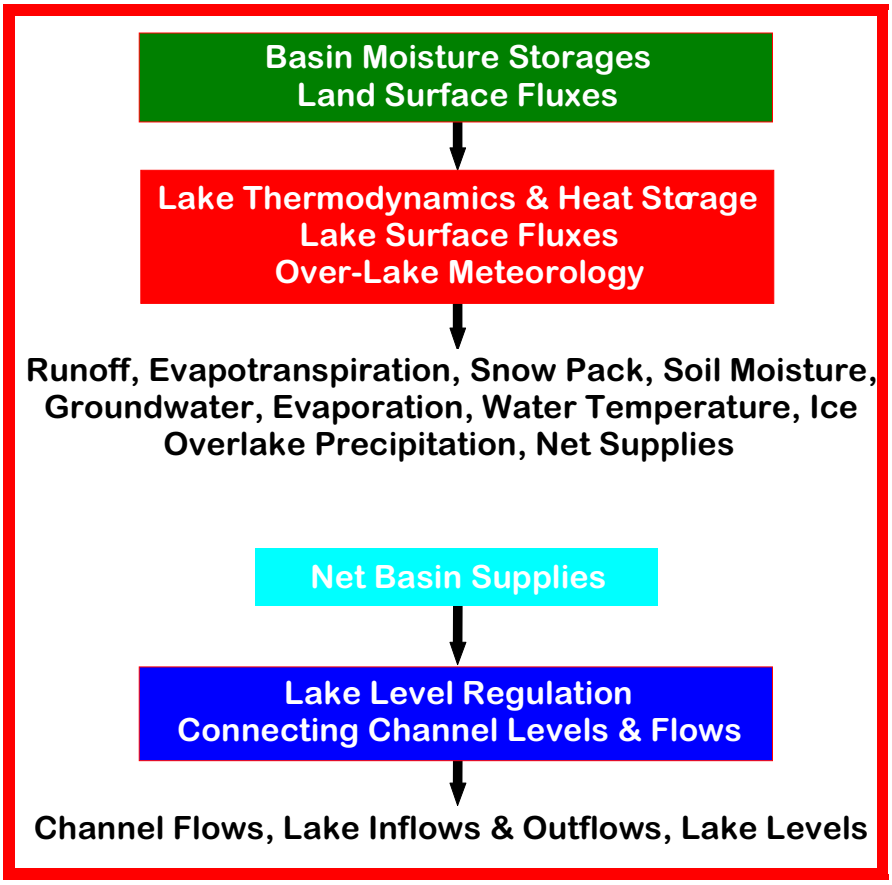
Need, Present Situation, & Potential:

The Great Lakes community requires extended forecasts of hydrology, water supply, and lake level probabilities over large areas and over time periods of 1 to 3 months and more. Probability forecasts allow decision makers to properly consider: some of the uncertainty inherent in forecasts, the wide range of possibilities always present, and *the risk associated with their decisions*. These forecasts require careful tracking of moisture and heat storages (to determine conditions initial to a forecast), by using both ongoing meteorology observations and available process models. These forecasts also should use available meteorology forecasts for the near- and long-term.

The present US and Canadian lake level forecasts project water levels for each Great Lake six months into the future; they are coordinated between the US and Canada to remove differences. Neither start with current moisture and heat storages or use weather forecasts.

Integrated Surface Models:

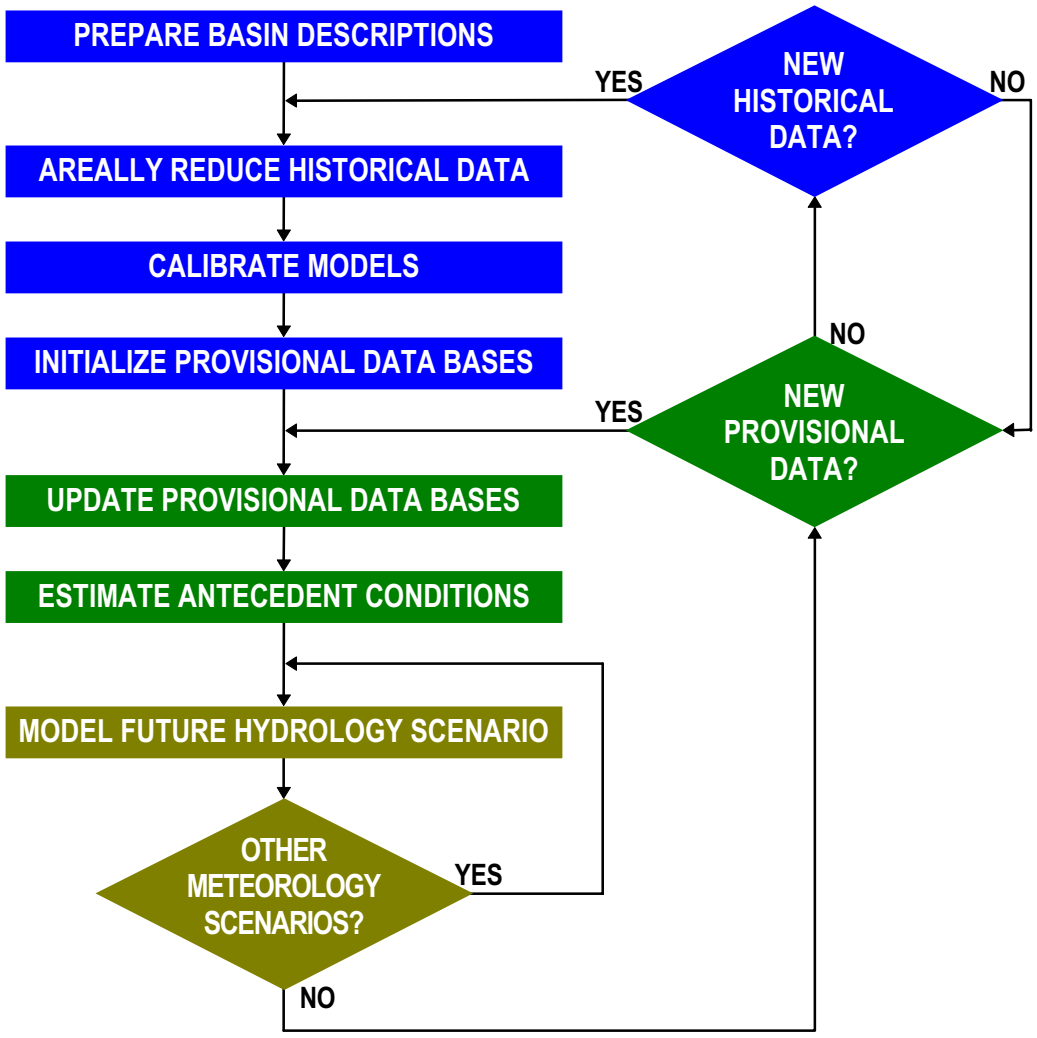


Fortunately (for forecasters) the Great Lakes possess tremendous storages of mass and energy and respond slowly to changes in meteorology. This makes it possible to forecast hydrology probabilities. The Great Lakes Environmental Research Laboratory (GLERL) developed, calibrated, and verified models for:

- basin moisture storage, rainfall-runoff, and evapotranspiration,
- overlake precipitation and lake thermodynamics, including heat storage, surface temperature, and evaporation,
- net basin supplies, and
- lake regulation, channel routing, and diversions and consumption.

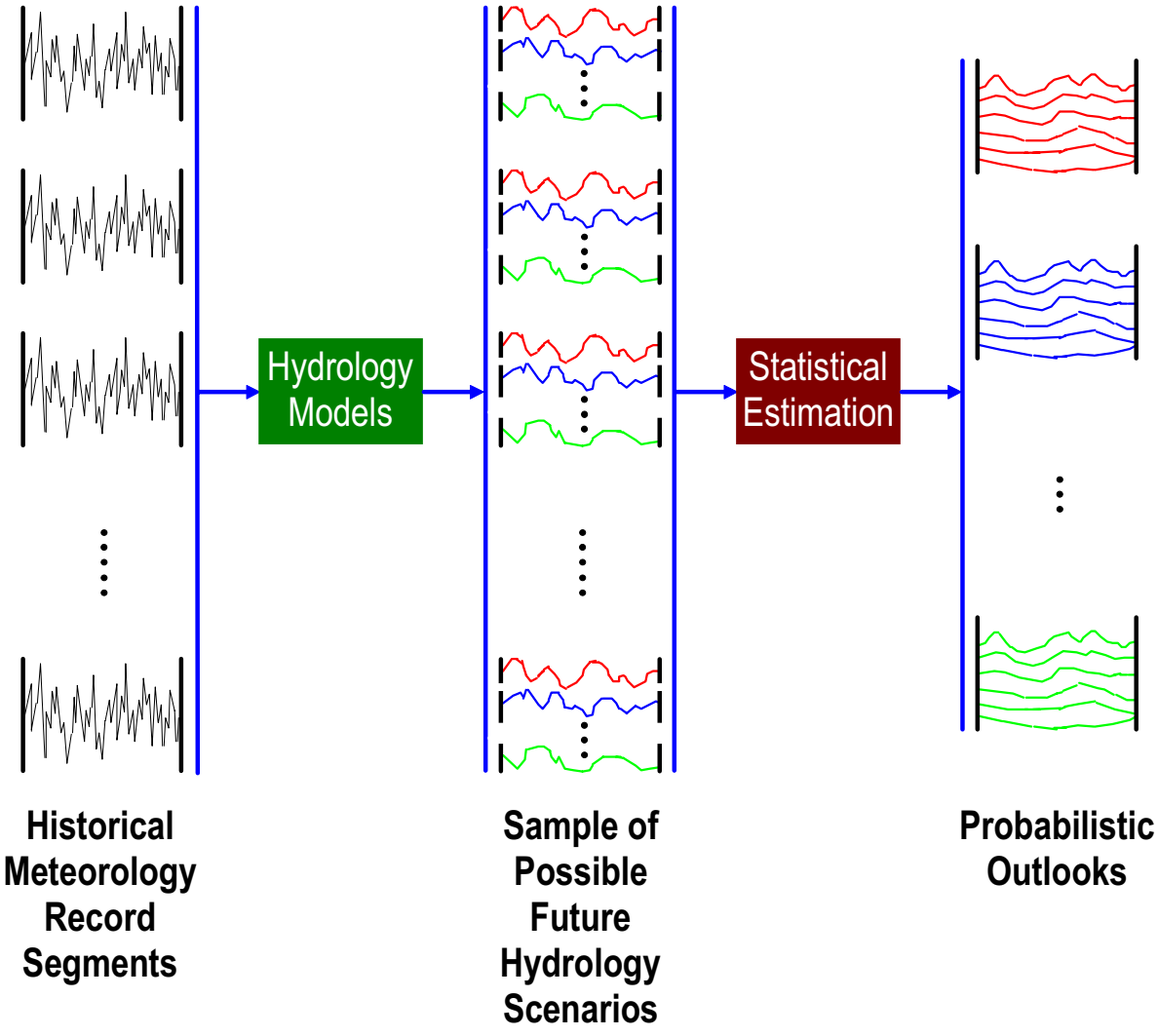
GLERL integrated these models into a system that is modularly-built, allowing upgrades to be "dropped in" as developed and tested. The model system is coupled with near real-time data to estimate current moisture and heat storages as well as 21 other hydrologic variables over 121 Great Lakes watersheds and lake surfaces. This model system forms the basis of GLERL's Advanced Hydrologic Prediction System (***AHPS***).

Deterministic Hydrology Forecasts:



The Great Lakes Environmental Research Laboratory earlier developed a semiautomatic software package for making deterministic forecasts of Great Lakes basin moisture storage conditions, basin runoff, lake heat storage conditions, lake surface water temperatures, lake surface evaporation, lake water supplies, and water levels. Daily provisional data allow estimation of initial conditions and a deterministic "forecast" may be made by simulating the hydrology from the initial conditions forward with a meteorology scenario.

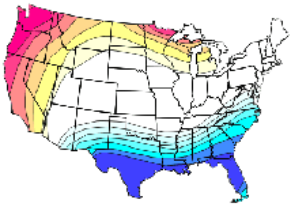
Probabilistic Hydrology Forecasts:



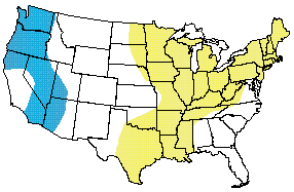
GLERL adapted this deterministic hydrology forecasting methodology to make probabilistic forecasts by considering historical meteorology scenarios (segments of the historical record) as possibilities for the future. The resulting set of modeled hydrology scenarios serves as a statistical sample for inferring probabilities and other parameters associated with both meteorology and hydrology. The resulting probabilistic hydrology outlooks properly considered antecedent hydrological conditions, but they did not consider other-agency predictions of meteorology.

Probabilistic Meteorology Forecasts:

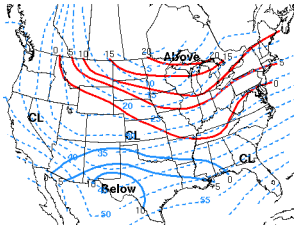
Multiple long-lead forecasts of meteorology probabilities of improving skill are now available for use. For the Great Lakes, these include:



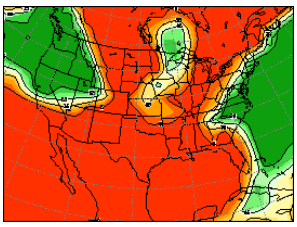
- **NOAA Climatic Outlooks**: 1-month & thirteen 3-month successively-lagged temperature & precipitation event probabilities, issued monthly at mid-month,



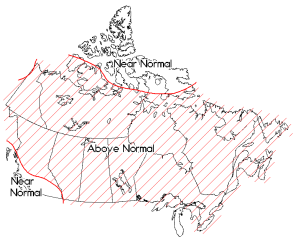
- **NOAA 5-Day Outlooks**: 6-10 day most probable temperature & precipitation events, issued every few days,



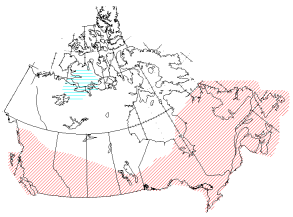
- **NOAA 8-14 Day Outlooks**: 8-14 day temperature & precipitation event probabilities, issued every few days,



- **NOAA Ensemble Forecast Products**: nine successively-lagged 1-day, 1-5 day, 6-10 day, and 8-14 day precipitation event probabilities issued daily,

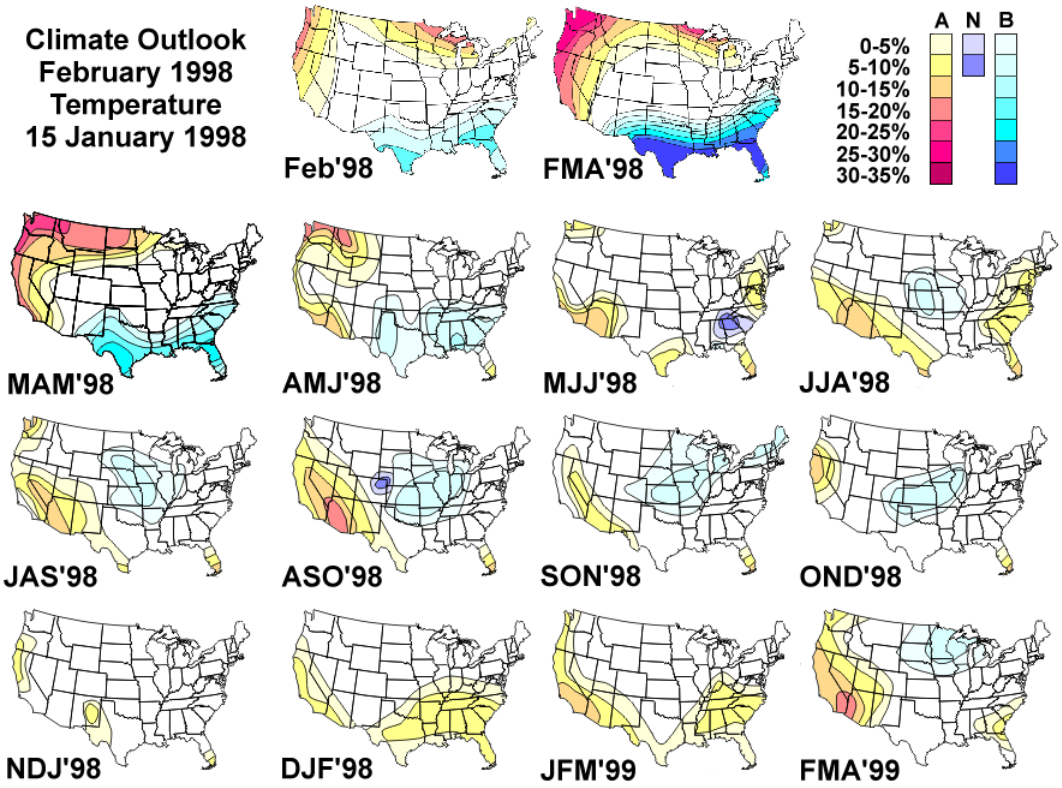


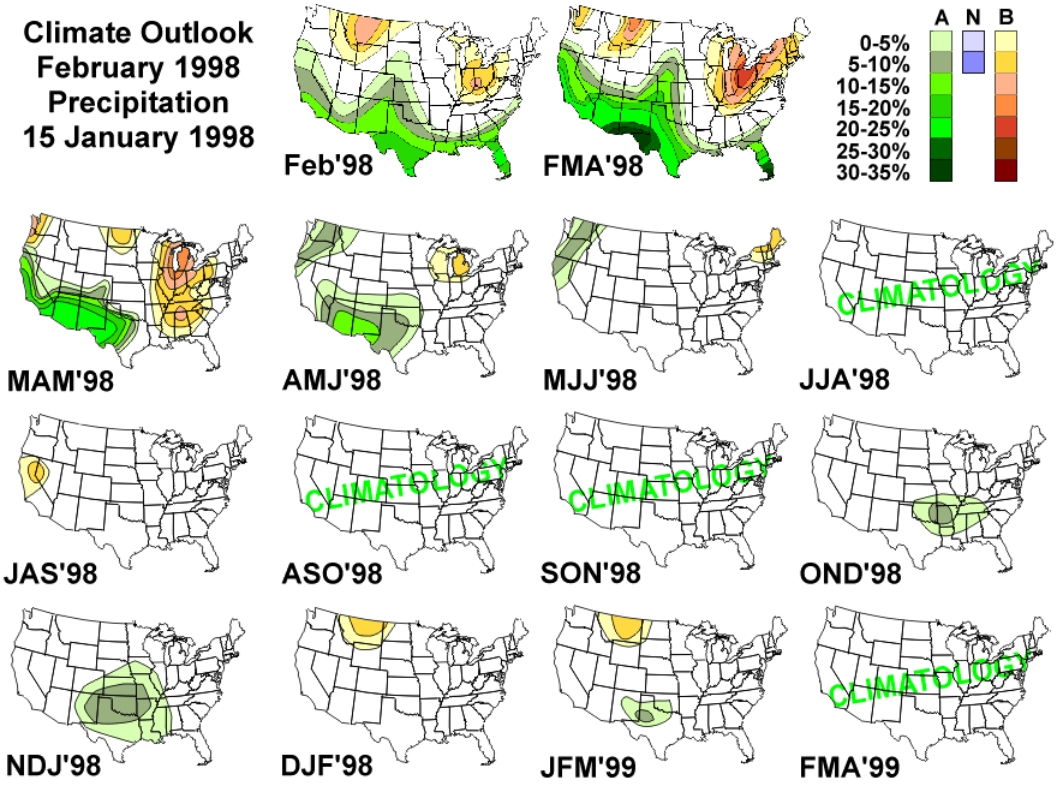
- **EC 30-Day Outlook**: 1-month most-probable temperature event, issued twice per month on the 1st & 15th,
- **EC 3-Month Outlooks**: 3-month most-probable temperature & precipitation events, issued quarter-annually,



- **EC Extended 3-Month Outlooks**: three experimental 3-month successively-lagged most-probable temperature & precipitation events, issued quarter-annually.

NOAA 1- & 3-Mo. Climatic Outlooks (Event Probabilities)

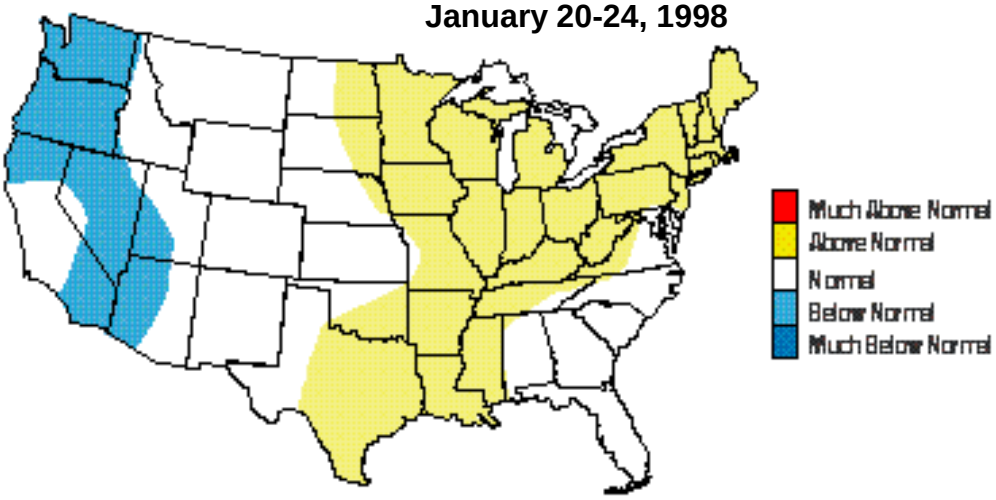




NOAA 6-10 Day Climatic Outlooks (Most-Probable Events)

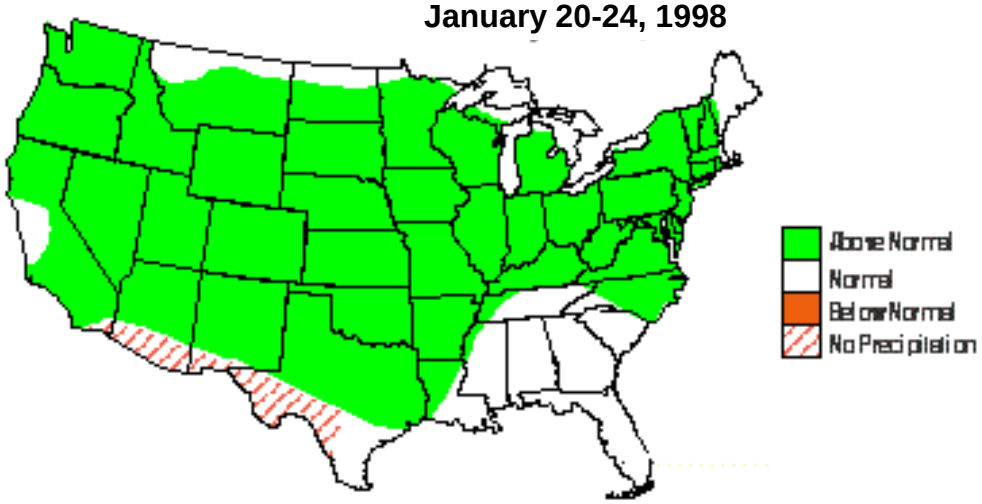
Six to Ten Day Mean Temperature Forecast

January 20-24, 1998

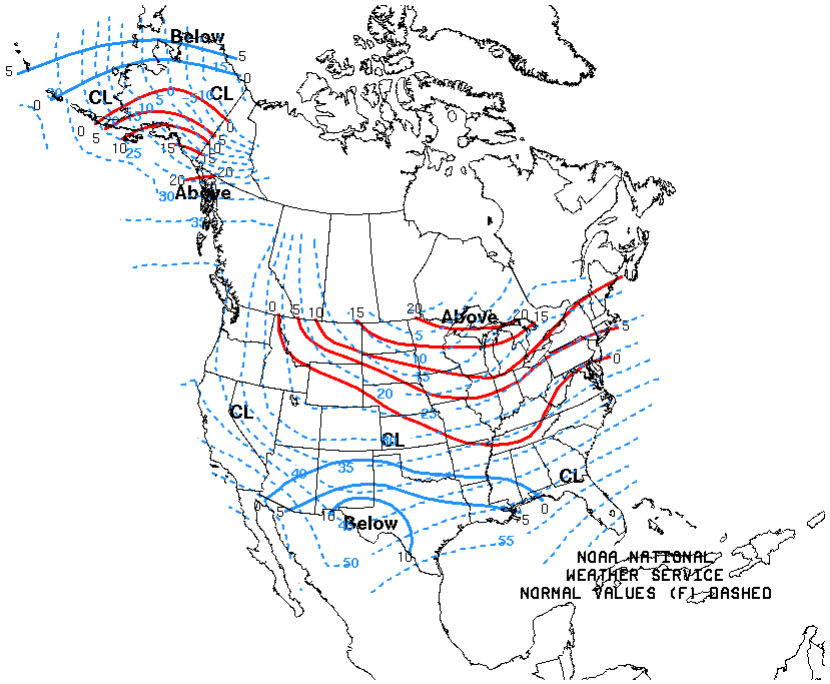


Six to Ten Day Mean Precipitation Forecast

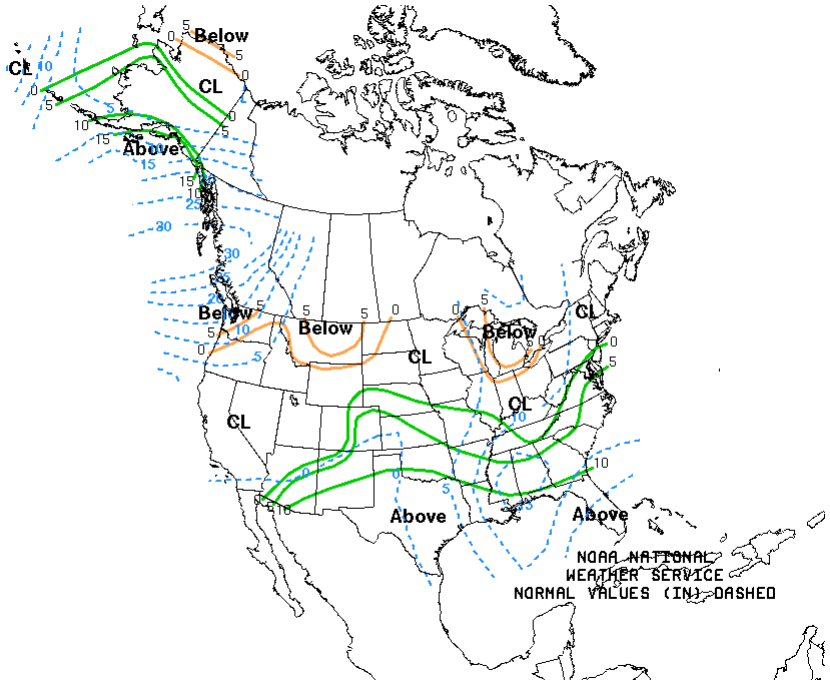
January 20-24, 1998



NOAA 8-14 Day Climatic Outlooks (Event Probabilities)



8-14 Day Temperature Outlook, 23-29 January 1998 (15 Jan'98)



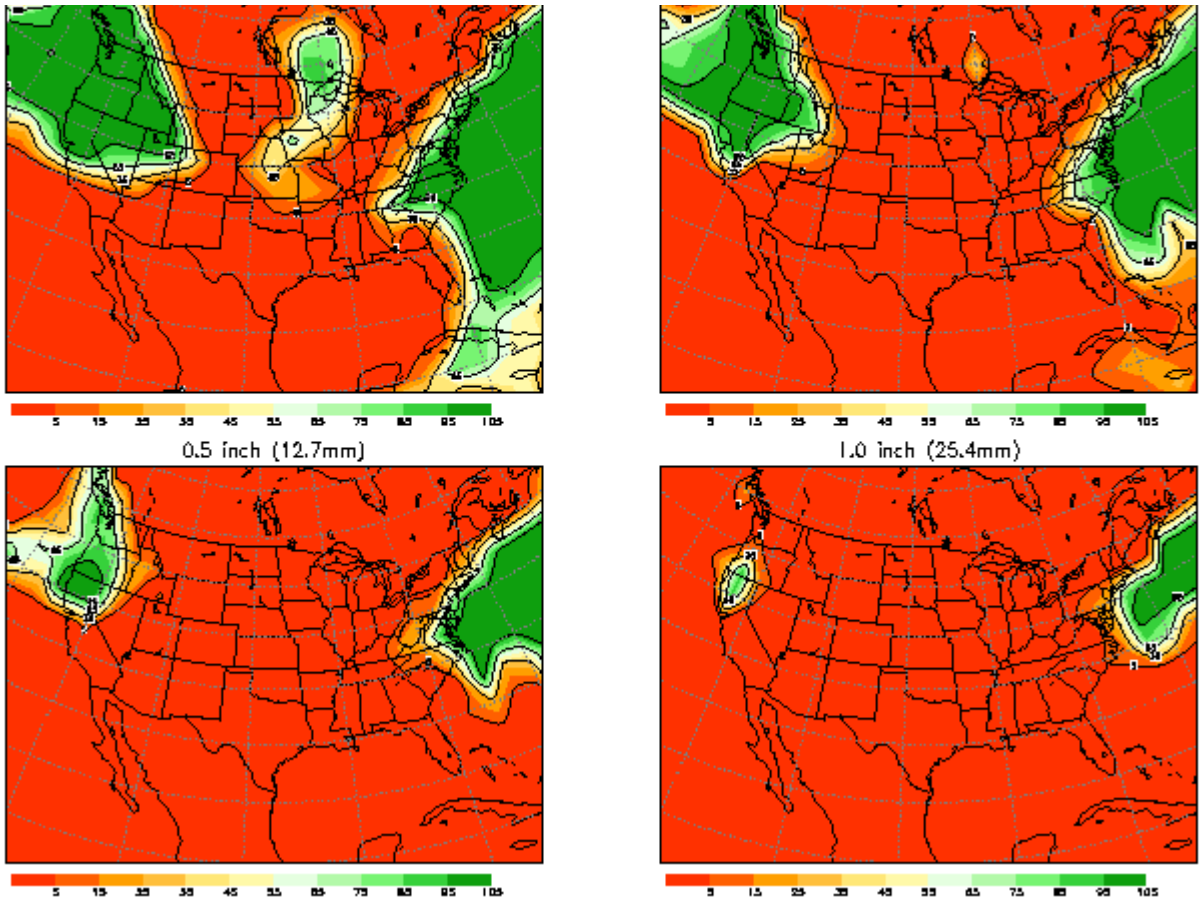
8-14 Day Precipitation Outlook, 23-29 January 1998 (15 Jan'98)

NOAA Ensemble Forecasts (Event Probabilities)

NOAA Ensemble-Based 24-Hr Probabilistic Precipitation Outlook

Initial time: 00 16 Jan '98; Valid Period: 12 16 Jan '98 - 12 17 Jan '98

(Probability of precipitation exceeding:)



Other ensemble forecasts also available include:

NOAA Ensemble-Based 1-5 Day Probabilistic Precipitation Outlook

Initial time: 00 16 Jan '98; Valid Period: 00 17 Jan '98 - 00 22 Jan '98

(Probability of precipitation exceeding:)

NOAA Ensemble-Based 6-10 Day Probabilistic Precipitation Outlook

Initial time: 00 16 Jan '98; Valid Period: 00 22 Jan '98 - 00 26 Jan '98

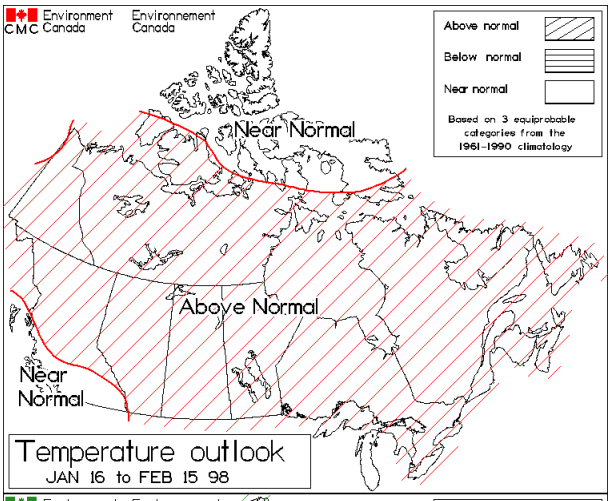
(Probability of precipitation exceeding:)

NOAA Ensemble-Based 8-14 Day Probabilistic Precipitation Outlook

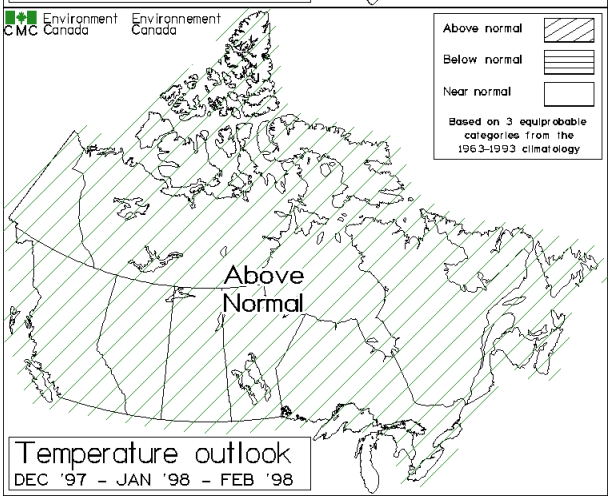
Initial time: 00 16 Jan '98; Valid Period: 00 24 Jan '98 - 00 30 Jan '98

(Probability of precipitation exceeding:)

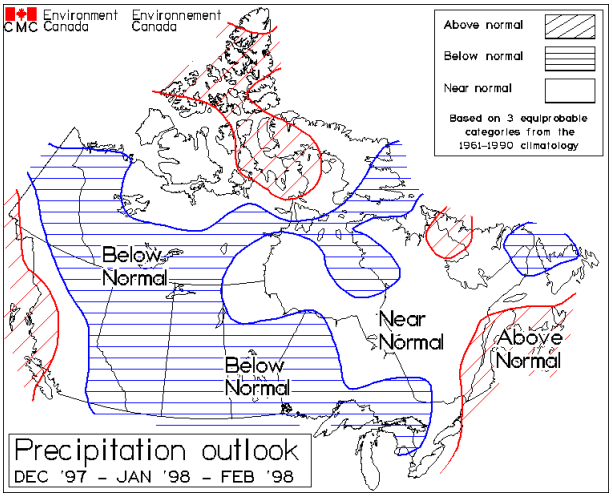
Environment Canada 1- & 3-Mo. Climatic Outlooks
(Most-Probable Event)



Environment Canada
30-day Temperature Outlook

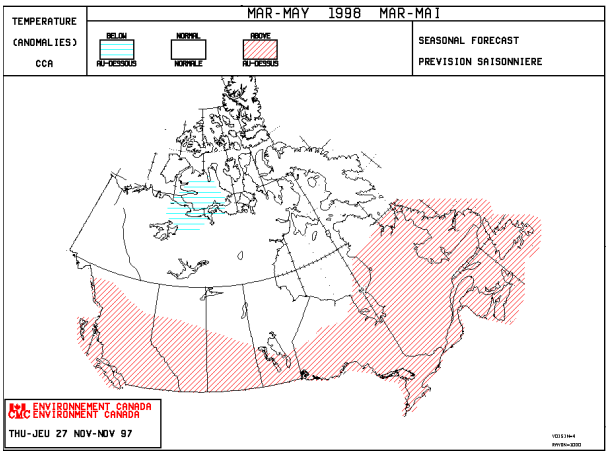


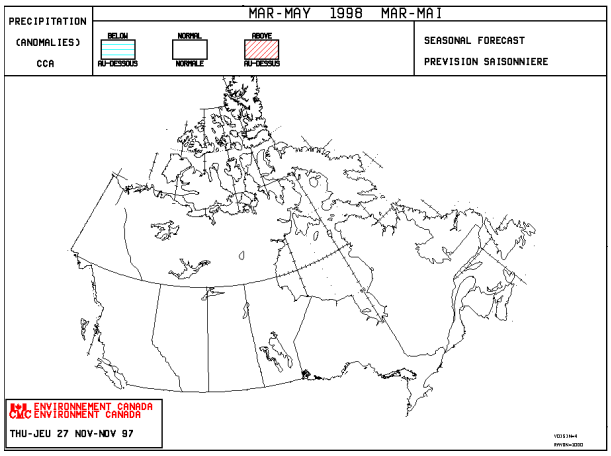
Environment Canada
3-mo Temperature Outlook

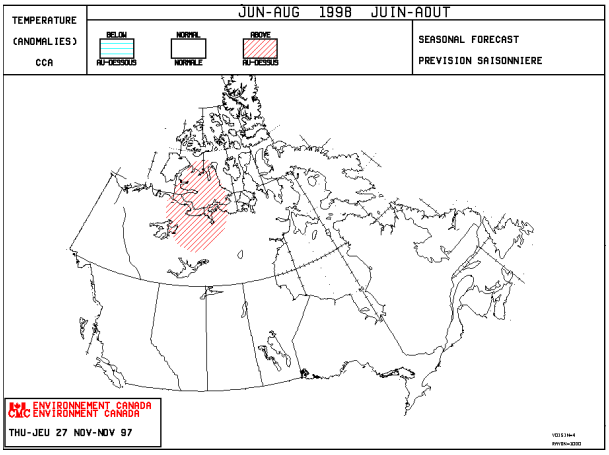


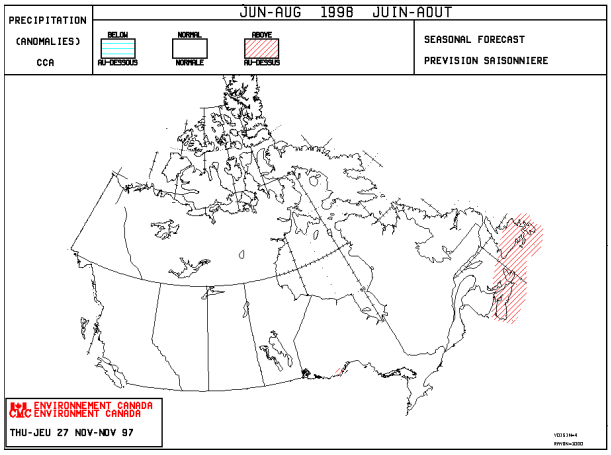
Environment Canada
3-mo Precipitation Outlook

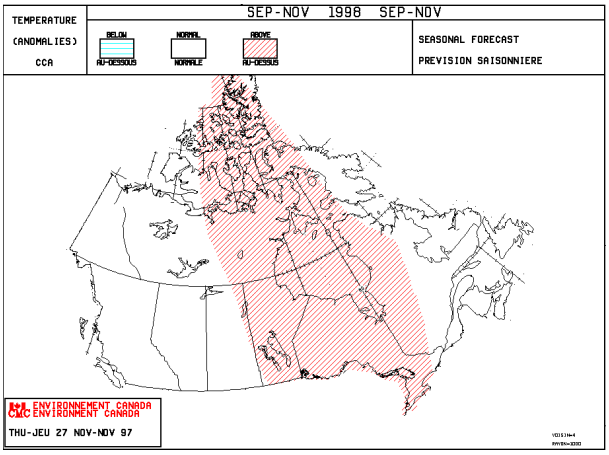
Environment Canada Extended 3-Mo. Climatic Outlooks (Most-Probable Event)

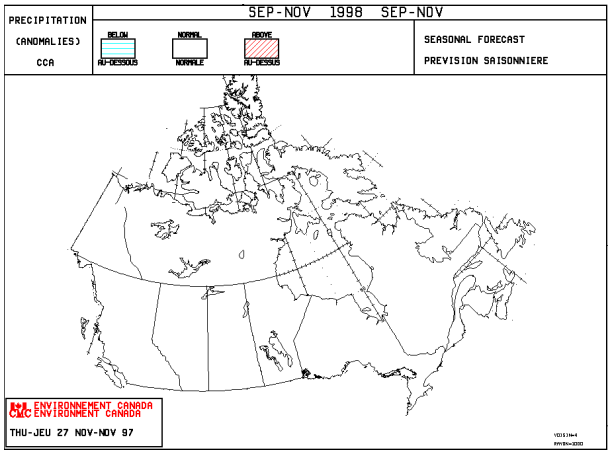






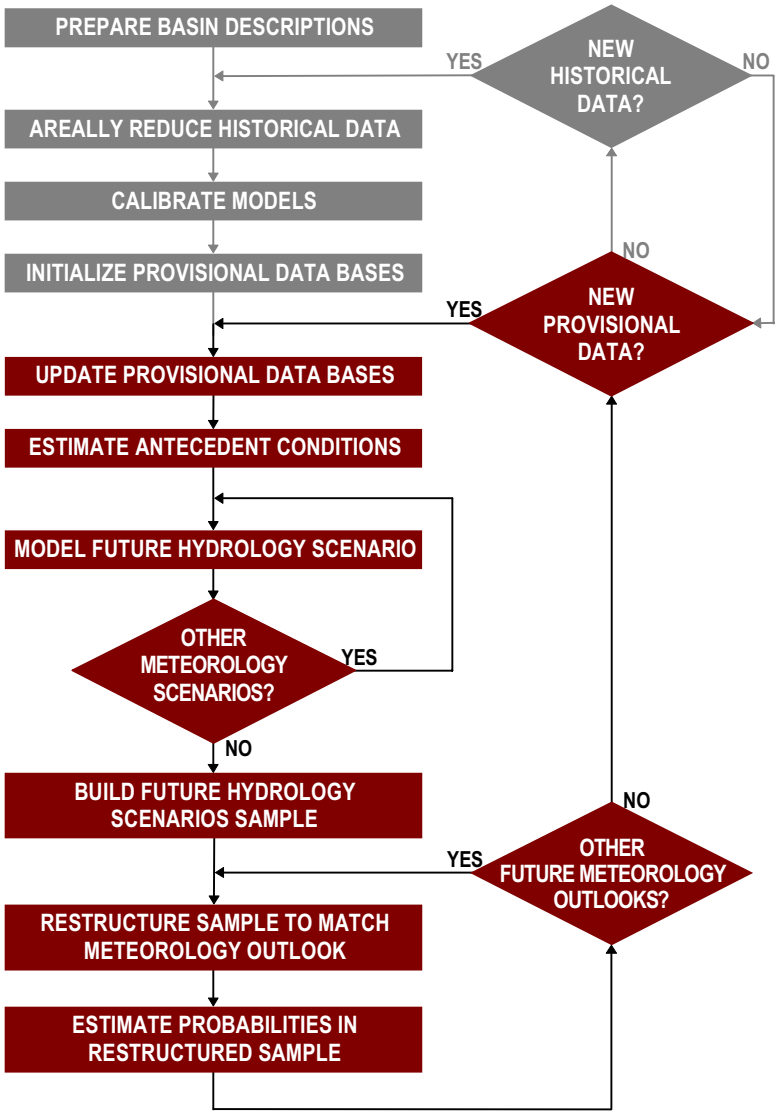






GLERL's Advanced Hydrologic Prediction System:

GLERL's ***AHPS*** properly incorporates these multiple-agency, multiple-period, multiple-area forecasts of meteorology probabilities by generating compatible forecasts of hydrology probabilities.

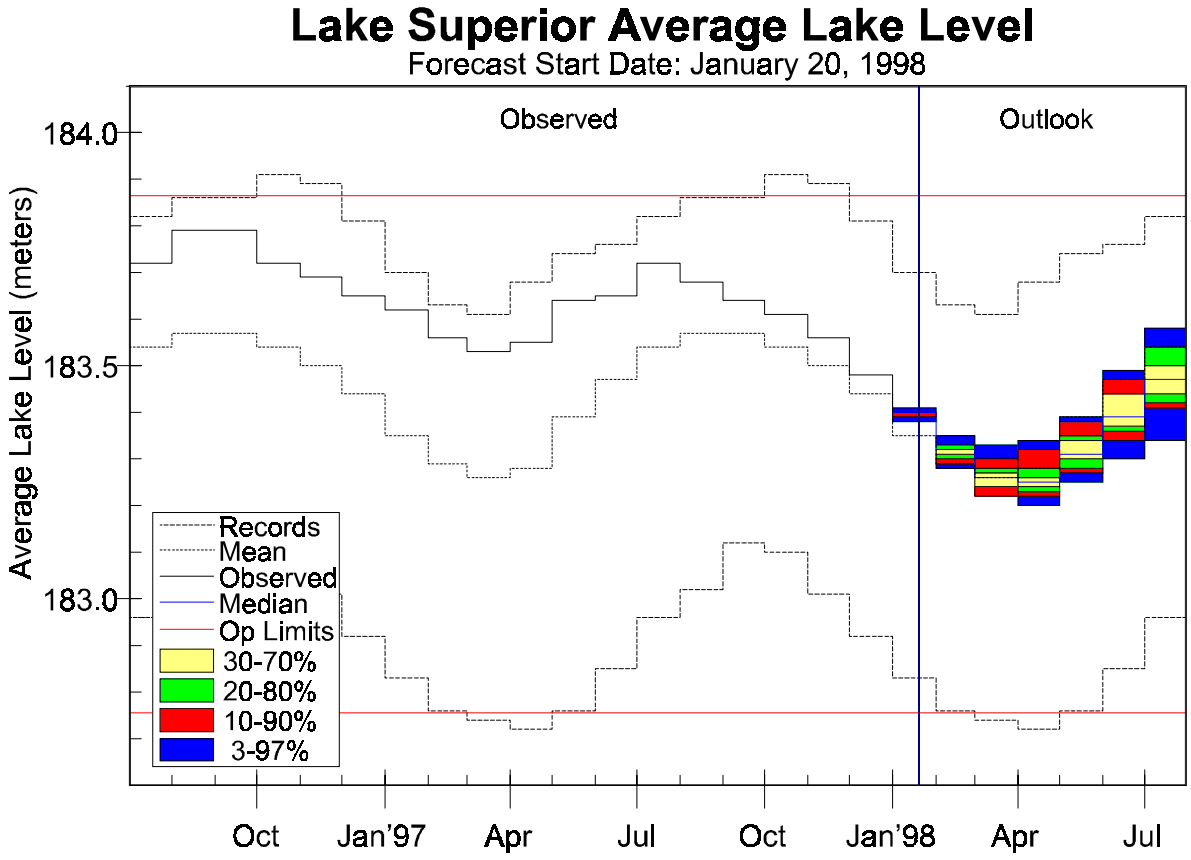


1) GLERL estimates current moisture and heat storages with their system of models from near real-time meteorology observations.
2) GLERL uses their system of models to estimate hydrology scenarios, as possibilities for the future, from meteorology scenarios taken from the historical record.
3) GLERL restructures the resulting set of scenarios (of meteorology and hydrology) to obtain relative frequencies of selected events matching the forecasts of meteorology probabilities.
4) GLERL infers hydrology probabilities from the restructured set of scenarios (of meteorology and hydrology).

This methodology can be applied to areas of the world where good physical process models and meteorology networks exist.

Forecasts of hydrology probabilities from the ***AHPS*** consider both current moisture and heat storages and use meteorology forecasts! The methodology provides an objective and open-ended means of jointly considering additional multiple-agency forecasts over multiple areas for multiple periods, as they become available.

GLERL's Probabilistic Outlooks:



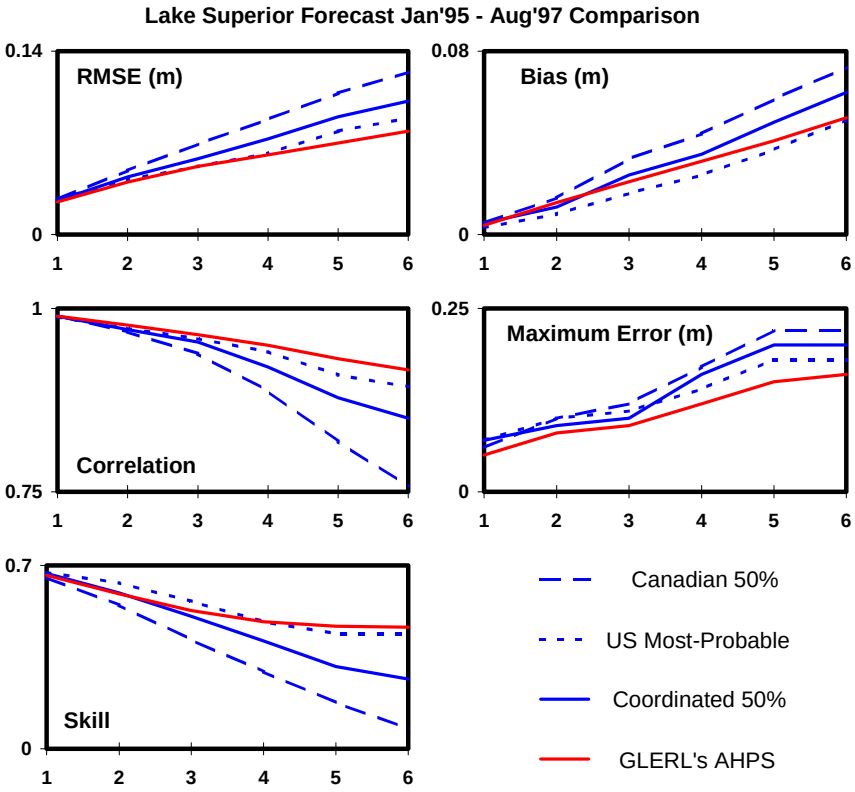
Uses current moisture & heat storages on 19 January 1998.
Uses EC 30-d T Outlook issued 16 January 1998.
Uses EC 3-m T & P Outlooks issued 1 December 1997.
Uses NOAA T & P Climatic Outlooks issued 15 January 1998.

GLERL makes experimental extended forecasts (6-9 months) every day for 23 different hydrology variables on all of the Great Lakes and Lake St Clair. Examples are available continuously on the World-Wide-Web at the Midwest Climate Center (**http://mcc.sws.uiuc.edu/glakes.html**) where forecasters run the package operationally. GLERL also makes experimental extended forecasts, like the one shown here, for beginning-of-month and average-monthly lake levels and outflows for all lakes; these were distributed to the International Joint Commission and Great Lakes managers during times of high levels. GLERL's ***AHPS*** forecasts are being evaluated by agencies of the International Joint Commission for use in the US-Canadian forecasts.

GLERL's Probabilistic Forecasts:

GLERL's forecasts of hydrology probabilities ***a)*** fully and correctly utilize long-range climate forecasts for multiple areas simultaneously, ***b)*** explicitly account for basin soil moisture and snow pack and lake heat storage and ice cover initial conditions, ***c)*** allow daily extended forecast generation, taking advantage of near-real-time data availability to offer continuously updated probability forecasts, ***d)*** utilize hydrology models in a modularly-built package that allows upgrades to be "dropped in" as developed and tested, ***e)*** provide probabilistic forecasts for each lake and river watershed, capitalizing on improving weather prediction skill and hydrometeorology observations, ***f)*** offer the proper manner in which to consider the wide range of possibilities that always exist, ***g)*** incorporate some of the uncertainty inherent in forecast estimates, and ***h)*** allow consideration of risk by decision makers.

The IJC Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data commissioned GLERL to do an evaluation of present coordinated lake level forecasts and GLERL's AHPS. We found:



- Considering antecedent conditions greatly improves a forecast.
- Considering available weather information generally improves extended estimation of extremes somewhat but may have more impact on a case-by-case basis.
- GLERL's AHPS generally has lower RMSE, higher correlation, better skill, and lower maximum error than the US Most-Probable, the Canadian 50%, and the Coordinated 50% forecasts of lake levels. Suggests that GLERL's AHPS generally has the smallest differences with actual levels each month of the forecast, best captures the timing of variations of lake levels, and is most-consistently best at the extremes over different periods.
- However, GLERL's AHPS often appears more biased than at least one of the other three methods. Suggests that we are generally under-predicting slightly during this time of high levels (both '93-'95 & '95-'97), but the other forecasts are less consistent from period to period.
- Currently building real-time evaluation tools with Detroit Corps.
- Currently coordinating forecast developments with the IJC, US, & Canada

The Buffalo Corps has funded us this year in a cooperative study

- to build L. Ontario & St. Lawrence water level forecast tools
- to link AHPS to their decision variables so they can advise regulation boards